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THE GEOLOGY OF THE OTWAY REGION, SOUTHERN VICTORIA

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Abstract: The physiography of the Otway Region, and its geological history following the mid-Mesozoic initiation of basinal deposition are outlined. Figures and Tables indicate details of stratigraphical relationships and biostratigraphical zonation. Some comments on palaeontology, structure and economic deposits are included.

PHYSIOGRAPHY

The Otway Region is physiographically divided into two major units, the Otway Ranges and the Coastal Plains. Their boundaries are relatively clearly defined, and the geology is readily observable from a fine road network, notably the Great Ocean Road which crosses the coastal segment.

The Coastal Plains extend up to 50 km inland and are bounded on the north by the Volcanic Plains (see Symposium 'The Basalt Plains of Victoria', Proc. R. Soc. Vict. Vol. 77, Pt. 2, 1964). Jenkin (1976) refers to two divisions of the plains: the Port Campbell Coastal Plains on the west and north of the Otway Ranges and the Torquay Coastal Plains to the east.

The flat or gently undulating Port Campbell Coastal Plains slope gently to the west with a steepening near the ranges and the Volcanic Plains. Height above sea level is usually below 100 m in the west, reaching to over 200 m at prominences on the east (e.g. Fergusons Hill). A prominent north-west to south-east drainage pattern south-east of Cobden on the Curdies River-Scotts Creek area has deep, steep valleys. There is semi karst topography with sink-holes near the northern margin of this area, and on the coast near Peterborough. Barred streams, for example the Gellibrand, Sherbrook and Curdies Rivers, are a feature of the Coastal Plains west of the ranges.

Abele (1971) regarded much of the Torquay Coastal Plains as the remnants of a plateau. This surface rises to the west to a maximum elevation of about 210 m near Wensleydale.

The most prominent feature of the Region is the Otway Ranges. A main north-east to south-west trending ridge runs for almost 100 km from Moonlight Head to north of Aireys Inlet in the east. Highest point is Mount Cowley (670 m) and the height of the main ridge is about 500 m for much of its length. Dissection is deep, with streams running off the ridge into the major Gellibrand and Barwon Rivers on the northern slopes, and short swift streams draining into the sea on the south. Waterfalls (e.g. Margaret, Melba, Erskine and Cumberland Falls) are prominent where these streams cross the strike of hard sandstone bands or where faulting has resulted in prominent scarps. Dissection is particularly marked near Apollo Bay along the Skenes Creek and Wild Dog Creek roads.

Shoreline profiles have been principally determined by lithology. Lower Cretaceous feldspathic sandstone and mudstone form broad shore platforms and cliffs of varying heights from Eastern View to Moonlight Head with some interruption by Tertiary sequences west of Cape Otway. Tertiary sand forms vertical cliffs at Anglesea. Older basalt forms a shore platform at Aireys Inlet. Tertiary limestone forms the famous rock stacks and indented coastline about Port Campbell. Quaternary aeolianite has a characteristic narrow shore platform and ramp of debris at Princetown and Hordern Vale. Recent dunes with shifting sandy areas back on to long beaches in several low-lying stretches.

GEOLOGY

Introduction

C. S. Wilkinson made one of the first exploratory journeys (1864) through the Otway Ranges, traversing the coast from Cape Otway to Peterborough. His report, with geological map, was published in 1865. Other early accounts of the geology of the ranges were by Krausé (1874) and Murray (1877). Sterling published several papers late last century, but little more was published until the major lithological study of Edwards and Baker (1943). Baker, in a series of stratigraphical papers (1944, 1950), mapped the westernmost Otway Ranges coastline and some of the Coastal Plains. Edwards (1962) in his final contribution

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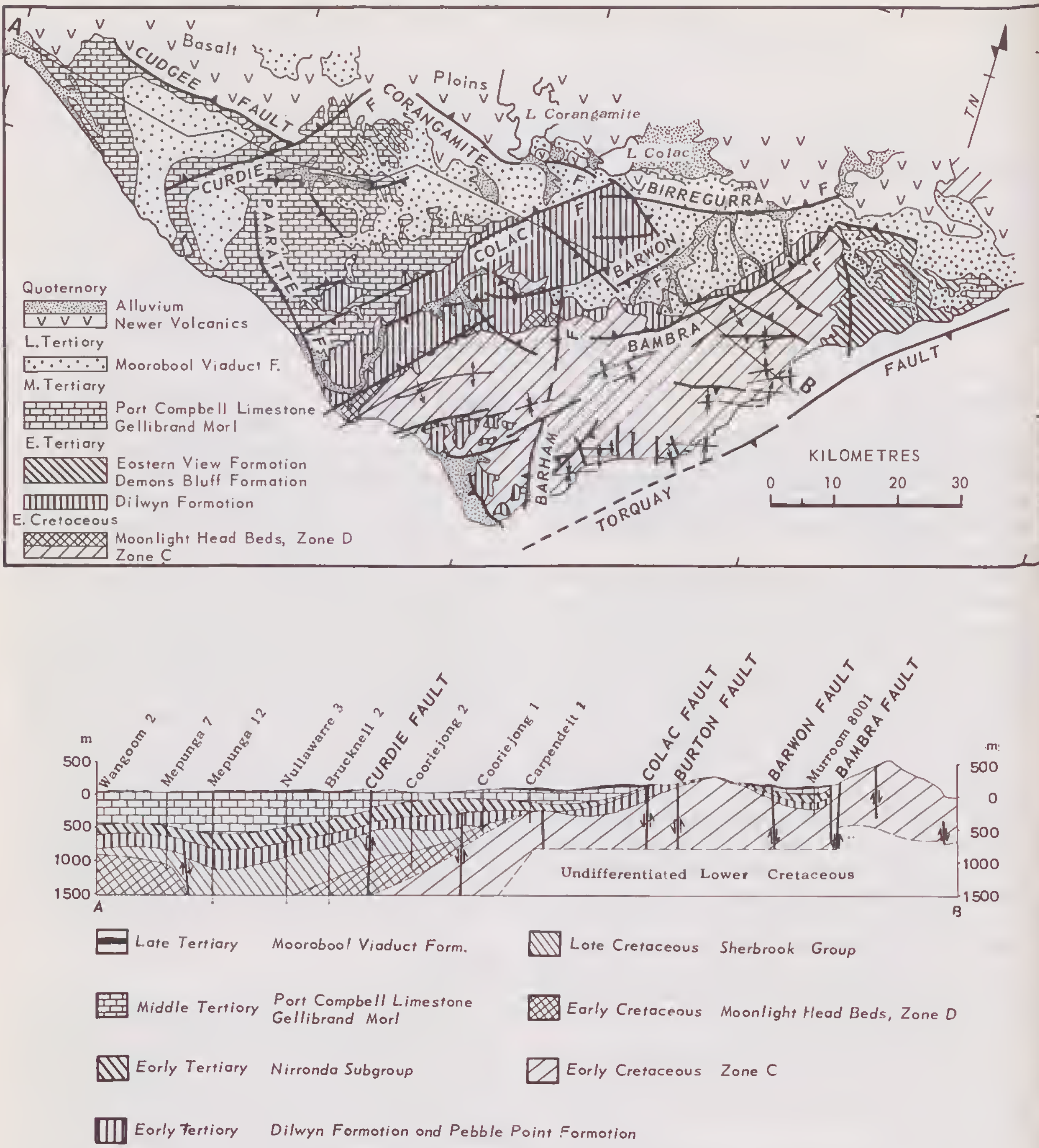

Fig. 1—Geological map Otway Region, and cross section.

Note: Cross section runs east-west, and is based on information from deep bores shown, and Otway Ranges outcrop geology. Western end A (see map) is near Warrnambool, eastern end B is at Lorne.

detailed the geology of the Lorne area, and Singleton (1967) reviewed the geology of the region. The most recent major paper on the ranges was a structural study by Medwell (1971).

Hall (1910) and others mapped the Anglesea coast, whilst Raggatt and Crespin (1955), Stach (1964) and Abele (1971) worked on the stratigraphy of this east coastal section.

In recent years there have been many palaeontological and biostratigraphical contributions, often based on studies of bore cores from the Coastal Plains. These include Singleton (1943), Cookson (1954), Cookson and Dettmann (1958), Carter (1958), Douglas (1960, 1969), Evans (1961), Dettmann (1963), Taylor (1964, 1971), Bock and Glenie (1965), Cookson and Eisenack (1965), Harris (1965), Glenie (1971). In addition there is much information in unpublished private company reports. Papers on economic geology are briefly discussed below.

Geological History

Little is known of the pre-Mesozoic rocks in the region, but schists in the Fergusons Hill No. 1 bore at about 3,500 m are believed to represent basement of possible Cambro-Ordovician age. Current theories of continental movements postulate that a drifting apart of the Gondwana or 'Southern Continent' which began in the Late Jurassic induced rifting in southern Australia. East-west grabens or troughs appeared (the Gippsland and Otway Basins in southern Victoria), and sediments from the northern Palaeozoic hinterland and uplands fringing the still adjacent Antarctica accumulated in a non-marine environment.

During the ensuing 30,000,000 years of *Early Cretaceous* time, sufficent sediment was supplied to produce feldspathic sandstone, mudstone and shale up to 3,000 m thick in places. In the Otway Basin these beds, the Otway Group, are present from the Mornington Peninsula to Robe (South Australia) and seaward, and have been intersected in many deep bores. However they outcrop only in the Casterton-Merino area and the Otway Ranges, and peripheral areas such as the Barrabool Hills. These outcrop areas are parts of the basin which have been subsequently uplifted and dissected.

A variety of non-marine depositional environments has been suggested for these Lower Cretaceous beds with the accent on alluvial and fluviatile conditions involving much re-working of sediment. The fossil flora is extensive and in places well preserved. The rocks and these fossils suggest braided streams and accompanying sandy areas, with vegetated swamps, fringing marshes, extensive more elevated areas with heavy fern and pteridosperms giving thick multi-storied ground cover and coniferous forests on the higher country. Chains of small lakes and deltaic conditions are indicated elsewhere (Douglas 1969). The animal kingdom may have been dominated by the dinosaurs, although no remains have been found closer than Cape Paterson in the Gippsland Basin (also Lower Cretaceous). There were fish similar to present day non-marine species, although again these are better known from Lower Cretaceous beds to the west and in Gippsland, as well as mussel-like shellfish and crabs, and a variety of insects including cicadas, bees, fleas, beetles and dragonflies. The birds recorded from feathers at Koonwarra in South Gippsland surely had their counterparts in the Otway area.

Accompanying volcanism has been postulated (Darragh & Bowen 1965), but basalt flows similar to those interbedded subsurface in the Otway Group further west have not been recorded here. Lower Cretaceous rocks are now well exposed along the Great Ocean Road from Eastern View on the east to Moonlight Head in the west, and in inland road cuttings. Cuttings inland are almost always of rock highly weathered to a buff colour, and the feldspathic sandstone on the ridges often weathers to an amorphous face, with bedding difficult to distinguish except where plant 'chaff' is prominently aligned. Coal bands usually a few cm in thickness are also useful as bedding indicators.

Little or no attempt has been made to define lithological units, although the fine grained sandstones and mudstones of the Moonlight Head Beds in the western flanks described by Baker (1950) contain a plant fossil assemblage (Zone 'D', see Table 3) readily distinguishable from the older assemblage on the ridge and other flanks of the Ranges.

There have been also only sporadic attempts to lithologically subdivide the subsurface section to the west, but the name Eumeralla Formation has gained some acceptance (see Benedek & Douglas 1976 and Table 1). Hence subdivision of both outcrop and subsurface is principally based on biostratigraphic evidence, viz. plant reproductive and vegetative remains. Spores and pollen assemblages have been used for the subsurface section, supplemented by megaplants in the Otway Ranges High. Several zones or assemblages with characteristic fossils have been delineated (see Table 3).

At the commencement of *Late Cretaceous* time, with the continental movement gathering momentum (Veevers & Evans 1973) shallow marginal marine conditions signalled the beginning of a new sedimentary regime. The Early Cenomanian Waarre Sandstone is the oldest formation in a transgressive-regressive series (Sherbrook Group) continuing into the Early Tertiary (see Table 1).

These Late Cretaceous beds do not now outcrop, but underlie Tertiary beds, in the Port Campbell Embay-

			Port Campbell area	Aire coast area	Anglesea area	
TERTIARY	PLIOCENE	Heytesbury Group	Moorabool Viaduct Formation	Moorabool Viaduct Formation	Moorabool Viaduct Formation	Torquay Group
	MIOCENE		Port Campbell Limestone		Puebla Formation Zeally Limestone Member	
			Gellibrand Marl	Sentinel Rock Clay Fishing Point Marl	Waurn Ponds Ls.Mem., Jan Juc Formation Point Addis Ls.Mem.	
	OLIGOCENE	Nirranda Subgroup	Clifton Formation	Calder River Limestone		
			Older Volcanics		Older Volcanics	
	EOCENE	Wangerrip Group	Narrawaturk Marl	Glen Aire Clay Castle Cove Limestone Browns Creek Clay	Angahook Member Demons Bluff Formation	
			Mepunga Formation		Anglesea Member	
			Older Volcanics	Johanna River Sand	Eastern View Formation	
	PALAEOCENE		Dilwyn Formation Pember Mudstone Member			
			Pebble Point Formation	Rotten Point Sand		
CRETACEOUS	UPPER	Sherbrook Group	Timboon Sand Member			
			Paaratte Formation			
			Nullawarre Greensand Member			
			Belfast Mudstone Member			
			Flaxman Formation			
			Waarre Sandstone			
	LOWER	Otway Group	Moonlight Head Beds	Moonlight Head Beds		Otway Group
			Eumeralla Formation			

TABLE 1.
TERTIARY AND CRETACEOUS STRATIGRAPHIC UNITS, OTWAY REGION

Unit	Lithology	Key Fossils	Biostratigraphic Assemblage**	
Zeally Limestone Member	Marine calcarenite	Foraminifera, echinoids, molluscs	P.tuberculatus	G 7
Puebla Formation	Marine calcareous silt, limestone, clay, marl	Foraminifera, gastropods, molluscs, bryozoans	T.bellus P.tuberculatus	E-H 6-8
Waurn Ponds Limestone Member	Marine bryozoal calcarenite, marl, clay	Foraminifera, bryozoans	P.tuberculatus	H 5
Point Addis Limestone Member	Marine marl, silt, limestone, bryozoal calcarenite, calcirudite	Foraminifera, echinoids, mollusca	P.tuberculatus	I-H 5
Jan Juc Formation	Marine marl, glauconitic calcarenite	Foraminifera, molluscs, echinoids	P.tuberculatus	I 4-5
Angahook Member	Tuff, basalt, breccia, sand, gravel, clay	Gastropods	P.tuberculatus	I-J 4
Demons Bluff Formation Anglesea Member	Marine carbonaceous silt, claystone, clay, sand, coal, pyritic and glauconitic shale	Foraminifera, ostracods, gastropods, echinoids, sporomorphs, microplankton	N.asperus	J-N 1-3
Eastern View Formation	Non-marine estuarine sand, gravel, silt, carbonaceous clay, brown coal	Plants (angiosperms), mollusca, sporomorphs	N.asperus Nothofagidites	N-Y?
Sentinel Rock Clay	Non-marine clay	Plants (angiosperms)		
Fishing Point Marl	Marine marl, clay, limestone	Foraminifera		F-H 6-8
Calder River Limestone	Marine calcarenite, quartz pebbles	Foraminifera	T.bellus P.tuberculatus	H-I 5
Glen Aire Clay	Marine bryozoal and sandy clay, carbonaceous clay	Foraminifera, bryozoans	N.asperus	K 3
Castle Cove Limestone	Marine limestone, sandy limestone, clay, marl	Foraminifera, shelly fossils	N.asperus	K-L 2-3
Browns Creek Clay	Marine marl, clay, glauconitic sand, carbonaceous silt	Foraminifera, molluscs, corals, echinoids, microplankton, sporomorphs	N.asperus	L-N 1-2
Johanna River Sand	Paralic sandstone, silt, conglomerate, sand, clay	Foraminifera	M.diversus N.asperus	N-U
Rotten Point Sand	Marine pebbly silty sandstone	Foraminifera, sporomorphs	L.balmei	
Moorabool Viaduct Formation	Sand, silt, ironstone, laterite, grit, limestone	Foraminifera, molluscs, plants (angiosperms)		
Port Campbell Limestone	Marine limestone, marl, chert	Foraminifera, bryozoans, brachiopods, echinoids, crustacea	T.bellus	C-E 8-12
Gellibrand Marl	Marine marl, limestone	Foraminifera, corals, molluscs, crustacea, microplankton	P.tuberculatus	F-H 6-8
Clifton Formation	Marine limonitic limestone, quartz sand, bryozoal sand	Foraminifera, bryozoans, molluscs, echinoids, fish	P.tuberculatus	H-I 5
Narrawaturk Marl	Marine marl	Foraminifera, bryozoans, brachiopods, molluscs	P.tuberculatus N.asperus (Narrawaturk Marl and Mepunga Formation)	I-K 3-4
Mepunga Formation	Marine limonitic calcareous sandstone, limestone, gravel	Foraminifera, molluscs, microplankton, sporomorphs		
Older Volcanics	Olivine basalt, titanaugite basalt, associated dykes, dolerite			
Dilwyn Formation	Paralic clay, shale, sandy dolomitic siltstone, sand, coal	Foraminifera, molluscs, fish, microplankton, sporomorphs	N.asperus P.asperopolus	L-Q 1-2
Pember Mudstone Member	Marine mudstone	Foraminifera, corals, molluscs, microplankton, sporomorphs	M.diversus L.balmei	R-U
Pebble Point Formation	Marine pebbly limestone, siltstone, silt, dolomitic sand, conglomerate, gravel	Foraminifera, corals, molluscs, fish, ostracods, microplankton, sporomorphs	L.balmei	U
Timboon Sand Member	Non-marine quartz sand, mudstone, coal			
Paaratte Formation	Paralic, deltaic, quartz sandstone, sand, shale, coal	Foraminifera, microplankton, molluscs, sporomorphs	T.lilliei to T.pachyexinus Paaratte Flora	D.pellucida to D.cretacea Y-XA
Nullawarre Greensand Member	Marine glauconitic and limonitic sandstone	Foraminifera, microplankton	T.pachyexinus to P.pannosus	N.aceras to A.parvum XA-XD
Belfast Mudstone Member	Marine, glauconitic mudstone	Foraminifera, gastropods, ammonites, belemnites, fish, microplankton, plants, (angiosperms, gymnosperms), sporomorphs	T.pachyexinus to P.pannosus	N.aceras to A.parvum XA-XD
Flaxman Formation	Marine and paralic glauconitic sandstone, sandy mudstone	Foraminifera, microplankton, sporomorphs	C.triplex to P.pannosus	A.parvum XB, XC, XD
Waarre Sandstone	Paralic and non-marine quartz sandstone, mudstone, carbonaceous siltstone	Microplankton, plants (coniferales, angiosperms, ginkgoales)	A.distocarinatus P.pannosus Waarre Flora	A.parvum XC, XD
Moonlight Head Beds	Non-marine light friable mudstone, feldspathic sandstone, carbonaceous bands	Plants (pteridosperms, filicales, liverworts, coniferales, angiosperms?), sporomorphs, insects	C.paradoxa Zone 'D'	
Eumeralla Formation	Non-marine alternating grey feldspathic sandstone, dark mudstone, thin coal seams	Plants (pteridosperms, filicales, coniferales), sporomorphs, fish	D.speciosus Zone 'C'	

TABLE 2. OUTLINE OF LITHOLOGIES, FOSSIL CONTENT AND BIOSTRATIGRAPHY OF UNITS SHOWN IN TABLE 1*.

* . Units of the Port Campbell area are listed, in stratigraphic sequence, below those of the Aire coast area, which in turn are below those of the Anglesea area.

** . See also Table 3. Largely based on Abele (1976).

ment (see Fig. 1.1 Wopfner & Douglas 1971) where they are over 1,700 m thick, and in deeper parts of the Otway Basin to the west. They contain foraminifera, microplankton and pollens used for stratigraphical distinction, and much rarer molluscs, ammonites, belemnites, fish scales, and plant remains.

The initial *Tertiary* unit was the Pebble Point Formation, a transgressive marine phase of the Wangerrip Group, with small outcrop areas on the coast near Princetown and present in bore sections west of the ranges. The most extensive outcrop is the Dilwyn Formation, a predominantly sandy unit which comprises the sands and gravel on the western flanks of the Ranges down to and across the Gellibrand River, and less important formation deposits north of Johanna and Cape Otway. The Dilwyn Formation conformably overlies the Pebble Point Formation and in its type section is calcareous sandy clay and silt, micaceous and pyritic, and conspicuously burrowed. Subsurface the formation is widespread, and generally thicker than the Pebble Point Formation. Both formations contain characteristic faunas. McGowran (1965) monographed the foraminifera. Spores and pollens and microplankton were studied by Harris (1965) and Stover (1973). Shelly fossils, particularly molluscs, are prevalent in the Pebble Point Formation but much rarer in the Dilwyn Formation.

There has been much confusion in stratigraphic nomenclature in this part of the Tertiary section. Suggested clarifications and detailed discussion are included in Abele (1976). Volcanic activity during the Eocene and Oligocene is represented by olivine basalt and dykes near Gellibrand, and several flows up to 200 m thick have been penetrated in bores.

The Nirranda Subgroup forms an important intermediate phase in Middle Tertiary sedimentation in the Port Campbell Embayment, but thickness is generally less than 200 m. The Mepunga Formation, essentially quartz sand, often calcareous and limonitic, but unfossiliferous, and the Narrawaturk Marl, richly fossiliferous, have been distinguished as units of this Subgroup.

The nomenclature of the Heytesbury Group with its constituent units and their stratigraphic limits is also confused, but consists predominantly of two transgressive marine units, the Gellibrand Marl, and the Port Campbell Limestone. These are almost 1,000 m thick in the Mepunga area, and contain extensive marine faunas including foraminifera. The Port Campbell Limestone forms the prominent and scenic coastal cliffs westwards from Princetown. Glenie (1971) included also in the Heytesbury Group the unconsolidated sands, gravels etc. of the Moorabool Viaduct Formation. These fringe the north central part of the Ranges.

In the Torquay Coastal Plains Tertiary sedimentation proceeded under a somewhat different regime, and a separate nomenclature has developed. Hence reconciliation with the areas adjoining the Port Campbell Embayment around the northeast of the ranges is difficult. The Torquay Tertiary sequence commences with the continental Eastern View Formation, which includes the brown coal measures at Anglesea (see below). This conformably underlies the Demons Bluff Formation and contains pollen assemblages (see Zonal scheme, Table 3).

The Demons Bluff Formation was subdivided by Raggatt and Crespin (1955) into three members of varied lithologies best exposed in coastal localities. Abele (1968) regrouped these in the Anglesea and Angahook Members. The Anglesea Member contains abundant foraminifera and rich pollen assemblages.

The Torquay Group, of marine origin, is represented by several units, the oldest of which, the Jan Juc Formation, conformably overlies the Demons Bluff Formation.

The Newer Volcanics of the *Quaternary* Volcanic Plains which abut the Otway region are not represented in the area. However consolidated Quaternary sediment is represented by highly cross-bedded dune limestones prominent at the mouth of the Gellibrand River at Princetown and the mouth of the Aire River at Hordern Vale and Glenaire. Unconsolidated Quaternary sands form extensive dune systems prominent east and west of the Gellibrand River mouth at Princetown and west of the Aire River mouth.

STRUCTURE

Elevation of the Ranges above the surrounding part of the basin seems to have begun in mid-Cretaceous time, and they have remained as a structural high. Although the postulation that they were an island throughout Tertiary time has been questioned (Hills 1940, Edwards 1962), some degree of pre-Tertiary uplift has gained considerable acceptance. See also Medwell 1977.

Medwell discusses the structure of the ranges in detail. He considers the basic structure to be a complex, flat-lying, block-faulted dome somewhat modifying his (1971) picture of a broad north-east trending anticline, with associated syncline on the south-east. Gunn (1974), using geophysical data, postulated three prominent structural trends in the region. A north-east trend in the ranges and to the west is most evident, and shown on geological maps of the area (e.g. Mines Dept. Vict., 1973), where major faults such as the Chapple Vale Fault delimit outcrop area and have great topographical expression. North-west faults, with less obvious, but still marked topographic expression are typified by the Benwerrin Fault, and the Barham Fault